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Reconfigurable Transmission-Type Beamformer

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Abstract – Beam forming, including focusing, power splitting and steering, has been demonstrated using a two-dimensional reconfigurable aperture to alter the transmission of propagating waves. The array consists of 5x5 unit blocks and each unit block contains 6x6 unit cells. Multiple beams, power splitting, beam steering angles of ±30°, focusing to 3-dB beamwidths of 10°, and defocusing to divergence angles of ±20° are demonstrated. Optimization of beamwidth and focal length with varying array configuration for the focusing architecture shows a focal length of 12.7λ and a minimum beamwidth of 10° at 5GHz.

Introduction

Modern radar, communications and radio astronomy require large-aperture antennas that are capable of producing multiple beams for simultaneous transmitting, targeting and tracking. Conventional beamforming networks employ power dividers and phase shifters to split the signal into multiple phased outputs. For example, the Globalstar satellite employs a 16-way power divider to feed a 91-element phased array and the Iridium system uses 106 patch elements to form 16 beams for earth coverage [1]. These architectures require isolators, filters and preamplifiers to maintain the signal-to-noise ratio for each element. Furthermore, such systems employ phase shifters based on stripline and waveguide technologies that are costly and complex.

An alternate approach is the transmission-type beamformer shown in Figure 1. In conventional beamforming networks, the signals originate from the surface elements of the beamformer itself. By contrast, the transmission-type beamformer alters the phase of incident waves, generated by an independent source, as they pass through the transmission aperture. This design differs from reflection-type architectures [2]. Depending on the reconfigurable metal patterns in the path, the array introduces phase shifts across the aperture to combine the waves coherently in the desired beam direction and shape. The array can be configured as a beam steerer, power splitter, or lens.

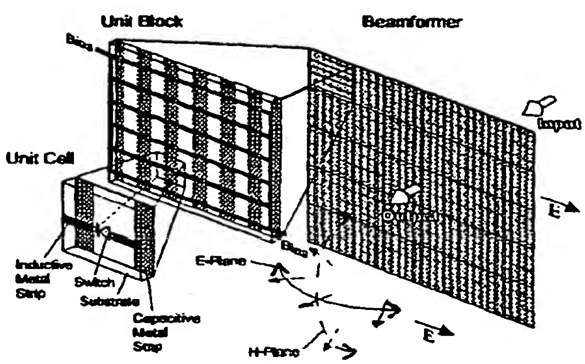

Figure 1: A 900-element reconfigurable transmission-type beamformer. The 30x30 array is divided into 5x5 unit blocks, each containing 6x6 unit cells.

Concept and Design

The beamformer, shown in Fig. 1, contains 900 elements consisting of periodic metal meshes on dielectric substrate. A switch within each element changes the unit cell reactance to impart a binary phase shift to the propagation waves. The unit cell phase shift is inductive when the switch is closed and capacitive when the switch is open. The elements of the 30x30 array are grouped into 5x5 unit blocks. Each unit block contains 6x6 unit cells. A single bias circuit controls each unit block; thus, the switches of each unit block are either all on or all off, providing binary phase states. The new architecture, utilizing unit blocks for beam forming, reduces phase coupling between unit cells, optimizes beam resolution and simplifies control circuits. The 25 unit blocks are programmable for steering, splitting or focusing. The architecture could function reciprocally as a front end for a power combining receiver or transmitter. This design promises to reduce bulk

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and weight and improve reliability over conventional beamforming networks by eliminating phase shifters and related components. Furthermore, the planar architecture makes it amenable to monolithic fabrication for high frequency applications.

A previous study [3] demonstrated the feasibility of transmission-type arrays for beam steering. Maximum E- and H-plane beam-steering angles of 12.5° and 20° were obtained, respectively. PIN-diode switches resulted in transmission losses of 6dB, whereas passive metal switches reduced losses to less than 2dB. Research is underway to develop monolithic microswitches [4] with pure metal-to-metal contacts that promise to decrease insertion losses.

The present study expands the transmission-type architecture to a large aperture for multi-function beamforming. In the design shown in Fig. 1, the unit cell period is 20mm and the widths of the inductive and capacitive metal strips are 2mm and 12mm, respectively. The strips are fabricated on opposite sides of the substrate to optimize binary phase states. The substrate has a dielectric constant of 2.33 and a thickness of 250μm. The method of moments predicts a shunt capacitance of 54.5fF and a shunt inductance of 7.8nH when the switch is open and closed, respectively, providing a phase shift of 42° at 5GHz.

Measurement Setup

The array was illuminated with a transmitting horn connected to an HP83592C source with an output power of +18.0dBm. The power varied by less than 3dB over the array surface, providing uniform illumination across the aperture. A receiving horn, connected to an HP437B power meter, was rotated about the grid to measure cut-plane patterns in 2.5° resolution over ±90°. The figures in this paper show the data between ±60° because the power levels beyond this range were negligibly small. The cut planes are taken in 10° increments over 180° for constructing 3-D patterns.

Planar Lenses

The array was configured as a converging lens by setting the switches of the center unit block to the open state and closing the remaining switches,

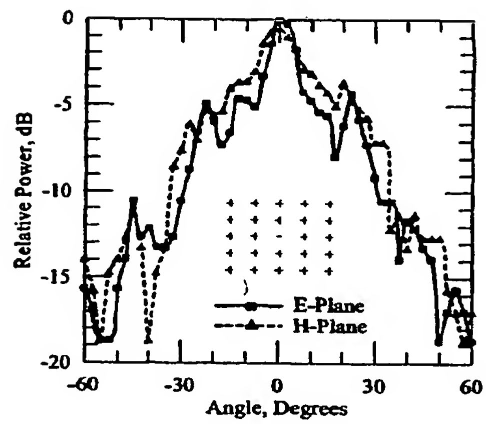

Figure 2: E- and H-plane patterns for the converging lens configuration.

producing negative and positive phase shifts, respectively. The legend in Fig. 2 shows the phases of the 25 unit blocks. Waves passing through the positively phased region are advanced with respect to waves passing through the negatively phased region. This phase difference produces focusing. The 3-dB beamwidth of the main lobe varies from 10° to 20° in the E- and H-planes, respectively, when the unit block size is 6x6.

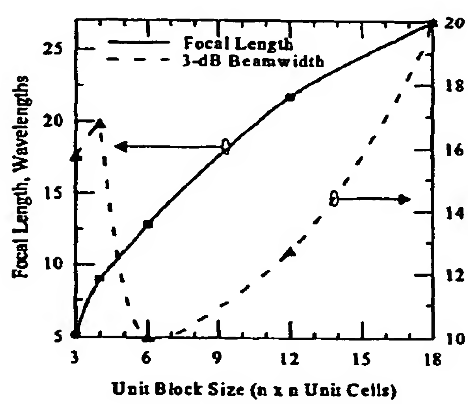

Figure 3: Focal length and 3-dB beamwidth versus unit block size of the converging lens.

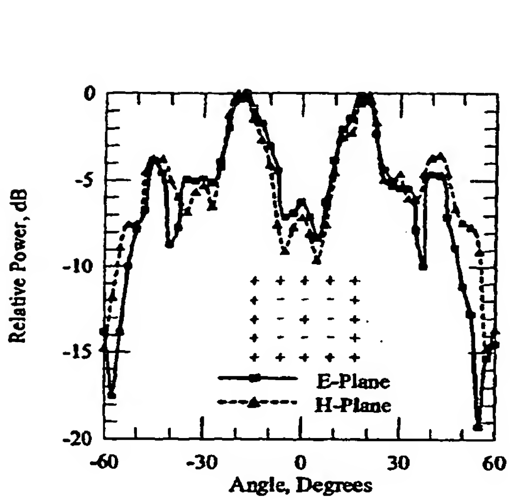

Figure 4: Diverging lens patterns in the E- and H-planes. The beam is defocused to ±20°.

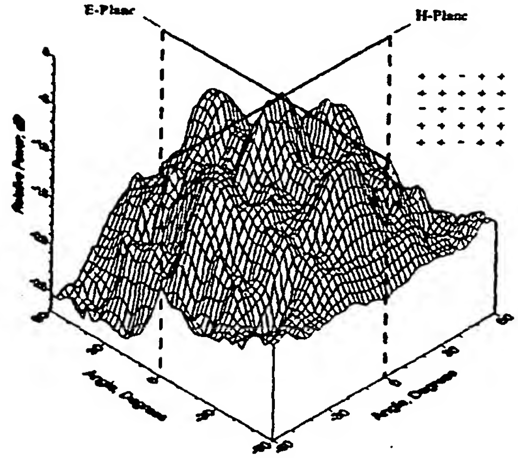

Figure 5: 3-D pattern of the multiple-beam steerer.

The 3-dB beamwidth of the converging lens was investigated by varying unit block size and focal length. Focal length is defined as the distance between the array and the receiver at which the 3-dB beamwidth is a minimum. Fig. 3 shows a 3-dB beamwidth of 10° for a unit block size of 6x6 and a focal length of 12.7λ. Larger unit block size preserves phase in the block and reduces phase coupling between adjacent blocks; however, this effect is limited by the fixed aperture size. Fig. 3 shows an optimum block size of 6x6 for an array with 30x30 unit cells. The figure also shows that focal length increases with unit block size.

Figure 4 shows the E- and H-patterns of the beamformer configured as a diverging lens. The beam diverges by ±20°. This divergence is a maximum for a unit block size of 6x6. The 3-dB beamwidth in each main beam is less than 12°.

Beam Steerer

The array was configured as a multiple-beam steerer by setting the unit blocks to the states shown in the legend of Fig. 5. This configuration combines the functions of both focusing and steering. The center beam is focused to beam-widths of 10° and 25° in the E- and H-planes, respectively, comparable to the focusing seen Fig. 2.

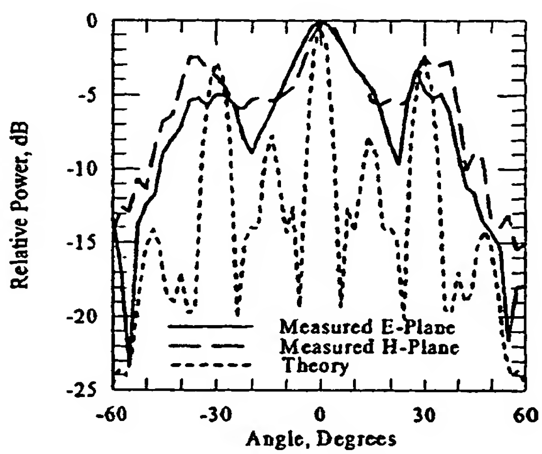

Figure 6: Measured and theoretical E- and H-plane patterns of the multiple-beam steerer.

The angles of the steered beams are ±30° in the E- and H-planes. The powers of the steered beams are approximately 3 dB less than the center beam. Figure 6 shows the measured and theoretical E- and H-plane patterns of the multiple-beam steerer. The theoretical plots are based on array theory [5].

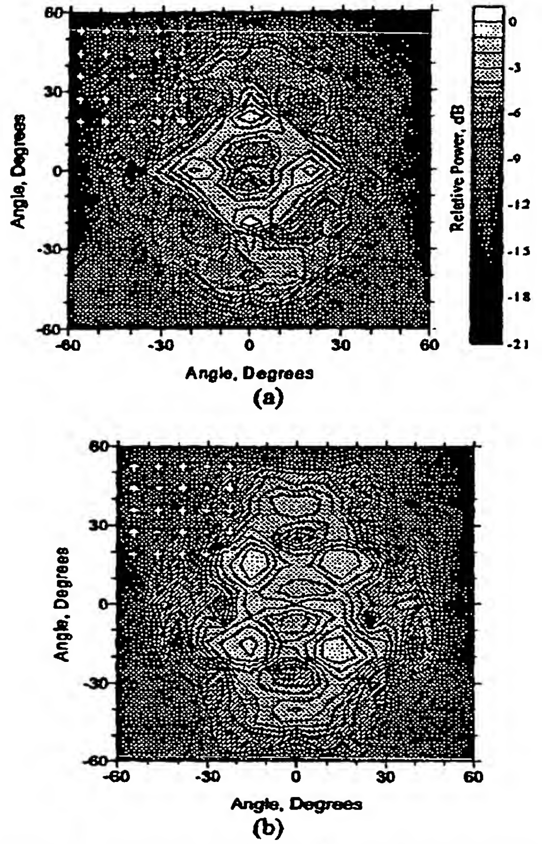

Figure 7: Patterns of the reconfigurable four-way power splitter.

Theory predicts beam-steering angles of ±30°, 3-dB beamwidths of 10°, and a power difference of 3dB between the steered and center beams. These calculations agree with measurements. Measurements show fewer nulls than theory, possibly due to limitations in the resolution of the pattern measurements.

POWER SPLITTER

The array was configured as a power splitter by setting the switches of four unit blocks to the open state as shown in the legend of Fig. 7(a). The resulting pattern shows the peaks at ±20° in the E- and H-planes. The switch states were then reconfigured to obtain the new pattern seen in Fig. 7(b). The peaks are now switched to ±20° in the 45° cut planes, demonstrating the functionality of the array for beam switching.

CONCLUSION

A reconfigurable transmission-type beamformer has been shown to produce beam focusing and defocusing, steering and power splitting. Optimum beamwidth and focal length of the focusing architecture have been established at 5GHz. Array dimensions will reduce to smaller scales at higher frequencies. The planar, transmission-type architecture has the potential to reduce cost and complexity compared to conventional beamforming networks and is suitable for monolithic batch fabrication for high frequency applications.

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